Blood Lead Levels in Toronto Children and Abatement of Lead-Contaminated Soil and House Dust

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ABSTRACT. South Riverdale in Toronto, Canada, underwent a lead-abatement program. In 1988, lead-contaminated soil was replaced at 970 properties, and in 1989, professional housecleaning for lead removal was conducted in 717 households. The effect of "abatement" on blood lead levels in young children was investigated. Data were analyzed from 12 cross-sectional blood-screening surveys that were conducted during an 8-y period in South Riverdale and in two comparison areas. Responses regarding behavioral, household, lifestyle, neighborhood, and environmental factors, all of which were gleaned from associated questionnaires, were also analyzed. Response rates varied between 32% and 75%. During the years between 1984 and 1992, blood lead decreased in all study areas. There appeared to be a minimal blood lead level of 2–3 μg/dl for urban Ontario children who were less than 6 y of age. The significant difference between South Riverdale and the control areas disappeared by 1992. Although abatement activity in South Riverdale was associated with an accelerated decline in blood lead levels, it was difficult to distinguish this from effects of decreased Toronto air lead levels or decreased smelter emissions. Within South Riverdale, abatement appeared to be associated with a slower decline in blood lead levels over time, likely the result of selection bias, soil mixing, or recontamination from the smelter. No difference was observed between the separate effects of housecleaning or soil replacement. The findings could neither strongly support nor refute beneficial effects of abatement.

CHILDHOOD EXPOSURE to lead arises from a variety of sources, including primary and secondary lead smelters. High lead levels have been reported[1–8] to occur in children who live near such smelters. Major exposure pathways for these children are thought to be air lead and contamination of soil and dust.

Few studies have been published in which programs to remove lead-contaminated soil have been evaluated. Demonstration projects are underway in several U.S. cities, including Boston, Cincinnati, and Baltimore.[9] In 1990 and 1991, two towns in Québec were the sites of large soil-removal programs. Goulet et al.[10] reported a drop in blood lead levels in children who were less than 6 y of age (i.e., from 10.3 μg/dl in 1989 to 5.2 μg/dl [geometric means] in 1991). During this time, the major point source was closed. In 1989 and 1991, Gagné[11]

Table 1.—Summary of Study Populations

	Year	Original no. children sampled	No. children excluded with reasons	Sample size used in this study	Study sample: % of target population
South Riverdale	1984	214	0	214	75.1
	1987	197	21, outside testing area 13, retest results 8, too old (> 5y) 1, missing blood lead data	154	58.6
	1988	176	20, from outside area 20, too old (> 5y)	136	46.7
	1989	204	11, from outside area 31, too old (> 5y)	162	68.6
	1990	184	15, from outside area 27, too old (> 5y)	148	61.7
	1992	134	5, from outside area 1, missing age data 18, too old (> 5y)	110	45.8
South Riverdale control	1988	158	1, too old (> 5y)	157	54.0
	1990	178	1, from outside area	177	47.7
Ontario Blood Lead Study (OBLS) control	1984	183	8, too old (> 6y) 2, too young (> 3y)	173	31.9
	1988	263	1, missing blood lead data 4, too old (> 6y)	258	57.8
	1990	249	0	249	51.7
	1992	228	3, missing blood lead data 1, from outside area 1, missing age data 1, too young (<3y)	222	43.5

laboratory participates in the U.S. Centers for Disease Control lead-analysis quality-assurance program.

Parent interviews. Information on risk factors was collected by phone within 1 mo of blood sampling, with three exceptions. The SR blood samples for 1984 were collected in the autumn of that year, but risk factors analyzed here were collected by phone interview in October 1986. Data on risk factors in SR in 1987 originated from questionnaires completed by parents at the time children provided blood samples. No risk factors, except age and gender of the children, were contained in the 1989 blood-lead dataset.

Environmental scanning. Environmental lead levels or sources were measured, when feasible or available, for each of the cross-sectional surveys, except for SR in 1987 and 1989. Soil lead values for SR were taken from the Ontario Ministry of the Environment (MOE) soil-sample database. These values were obtained from every house prior to 1987 to determine eligibility for soil replacement. This approach, however, had an important implication for the study: SR soil lead levels in the study included only samples taken prior to abatement, not during the year that blood sampling occurred. In 1988 only, soil sampling in SRC was conducted by the MOE at houses of all children who provided blood samples. In 1984 and 1988, soil sampling was also conducted by the MOE at schoolyards at the five OBLS schools. Data on airborne lead, dust-fall lead, and traffic density were collected from databases maintained by government agencies.

Participation in the lead-abatement program. Approximately 970 properties in SR had soil lead levels that exceeded 500 ppm and, therefore, qualified for replacement. Very few individuals who resided on these properties refused to participate. At each property, the top 30 cm of soil was removed from contaminated sites. The main contract for soil replacement was initiated in May 1988, and it was completed in October 1988. All residents in the soil-testing area, regardless of soil lead level, were offered professional housecleaning services to remove accumulated dust. The service was offered to 1 029 households, and 717 (69.7%) households agreed. Cleaning occurred from April to November 1989. Data on soil replacement and housecleaning were taken from administrative databases.

Data analysis. Logarithmic transformation (to base e) was conducted for blood lead values because distributions were typically log-normal. Logs were also calculated for all the environmental lead variables measured (e.g., airborne lead, soil lead). In bivariate analyses, these transformed variables were always equal to or greater than their arithmetic forms in correlation to the log of blood lead.

All statistical analysis was conducted with SAS-PC (version 6.04) and mainframe SAS (version 6.08).[22] Descriptive statistical analysis included calculation of the mean of the log-transformed blood lead, followed by taking its antilog. We calculated 95% confidence intervals in log form, after which they were converted. Relationships between variables were estimated with

Table 2.—Summary of Blood Lead Results

Study group	Year	Sample size	Mean (μg/dl)	95% confidence interval (μg/dl)	Children at or above: 10 μg/dl *n*	%	20 μg/dl *n*	%
South Riverdale	1984	214	14.0	13.2–14.9	183	85.5	39	18.2
	1987	154	10.9	10.1–11.7	87	56.5	17	11.0
	1988	136	9.3	8.7–9.9	58	42.7	1	0.7
	1989	162	6.5	6.0–7.1	29	17.9	3	1.9
	1990	148	6.4	5.9–6.9	24	16.2	1	0.7
	1992	110	3.9	3.5–4.4	8	7.3	0	0.0
South Riverdale control	1988	157	7.1	6.6–7.7	36	22.9	3	1.9
	1990	177	4.2	3.8–4.6	7	4.0	0	0.0
Ontario Blood Lead Study (OBLS) control	1984	173	11.9	11.3–12.6	119	68.8	13	7.5
	1988	258	5.1	4.8–5.4	18	7.0	2	0.8
	1990	249	3.6	3.3–3.9	8	3.2	1	0.4
	1992	222	3.5	3.1–3.8	18	8.1	2	0.9

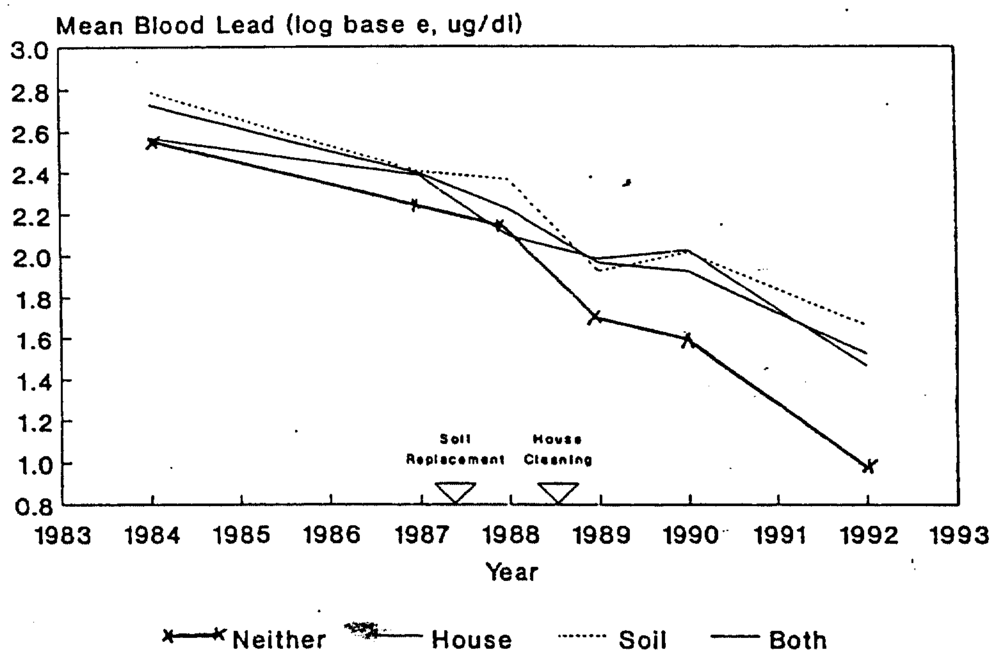

Fig. 2. Geometric mean blood lead levels, by year and abatement group, South Riverdale only. House = housecleaning only, Soil = soil replacement only, Both = both components done, and Neither = neither component done.

limits were used, the mean would have been expected to lie between 5.7 and 8.2 μg/dl. The observed mean, however, was 3.9 μg/dl.

Slopes, or changes in (the log of) blood lead over time, were also compared. Within SR, the change in blood lead levels from 1984 to 1987 (a "baseline" slope before any intervention) was not significantly different from the change in 1987–1988, the time period during which soil replacement occurred ($p < .20$). Compared with the same baseline period, however, blood lead dropped significantly more quickly in 1988–1989, during the housecleaning period; in 1987–1989, covering both interventions; in 1987–1992, covering both interventions and the long-term effect; and in 1989–1992, the postintervention slope ($p < .0005$ as to all). Adjustment for the original soil lead level did not change these results.

Prior to abatement (i.e., 1984–1987), blood lead levels in SR did not decrease as quickly as levels in the OBLS control area ($p < .05$). Subsequent to abatement (i.e., 1988–1992 or 1990–1992), blood lead levels in SR dropped significantly more quickly than in the control area.

Effect on individuals within the SR community. Potential impacts on children's individual blood lead levels were considered in this analysis. Time patterns in during (1984) and after (1992) abatement procedures. Blood lead levels dropped significantly over the 8 y; the mean in the no-abatement group was, on average, significantly lower than in the other groups, and the no-abatement group dropped significantly more quickly (Table 3, model 5). Adjustment for soil lead or home heating did not change these observations (Table 3, models 6 and 7).

In before/after comparisons, there was no evidence of a dose-response effect. The trend over time in children who resided in homes around which all soil had been replaced was not significantly different from the trend in children who lived in homes around which only part of the soil (e.g., front yard only) was replaced. This remained consistent after adjustment was made for confounders. The same was evident for children whose entire homes were professionally cleaned or for children whose homes were cleaned partially (i.e., no duct cleaning).

The final blood lead levels in 1992 were examined alone. No longer was SR significantly different from the control area (OBLS). This was true for all ages ($p < .13$), as well as for 3–5-y-olds sampled in both areas ($p < .48$). Within SR, there remained a significant difference among children who lived in homes that had undergone different abatement activities ($p < .0001$). The no-abatement group had blood lead levels lower than the other three groups; the three groups with abatement were not significantly different from each other. When we compared the OBLS control mean with the means of the four abatement groups, the mean fell between the no-abatement group and the other three groups. Although there remained a significant difference in overall means ($p < .002$), the OBLS group itself, being in the middle, was not different from any abatement group in SR. In the 3–5 y olds alone, the difference between groups was not significant ($p < .14$). Adjustment for soil lead, electric heating, or playing in the yard did not result in a change in the conclusions stated above.

Soil and dust lead can spread from yard to yard. In our study, however, a child's blood lead level was not associated significantly with soil replacement in an adjacent neighbor's yard. This was true regardless of soil lead around the child's own home or of any abatement activities there.

Discussion

The decrease in blood lead during the 1980s accorded with reports from other areas.[19,23,24] The most likely major factors responsible were removal of lead from gasoline and decreased lead exposure from canned food. The fact that all gas sold in Ontario was lead free by 1990 corresponds to the levelling out observed in the OBLS control area. Education or behavioral interventions might have permitted levels even lower than 2–3 μg/dl, because the no-abatement group in SR had a lower (but not significantly) mean blood lead in 1992 than did children of similar ages in the OBLS control. Also, many children in the OBLS schools lived in the lower-socioeconomic areas of Toronto; this might have predisposed them to blood lead levels that were higher than the levels in Ontario children in general.

Three observations in SR as a whole suggested that abatement (i.e., soil replacement in 1988, housecleaning in 1989) was associated with an accelerated decrease in blood lead over time. These observations included an SR mean in 1992 lower than that extrapolated from its initial trend; significant changes in time trends after 1988; and, after 1988, more rapid blood lead decrease in SR than in controls after 1988.

On the other hand, the acceleration might have occurred independent of the abatement program. The OBLS control area, originally included to address this question, was of little help because of unforeseen levelling out at low blood lead values. In Toronto, the decline of lead in suspended particulates also accelerated during 1987 and 1988.[25] This decline made it particularly difficult to ascertain the contribution of abatement. In 1992, the activity and emissions of the smelter decreased greatly; perhaps this contributed to the decrease in blood lead levels of children from SR during the time period 1990–1992.

The individual data for children in SR yielded an impression that differed from the analysis of SR as a "community." Children who experienced any abatement exhibited a slower decrease in blood lead levels than children without abatement. This could not be explained by the confounding factors measured in these surveys. Other factors (not measured here) might have been responsible; the best multiple regression models accounted for only 47–55% of the variation in blood lead (ignoring correlation within children).

It was unlikely that the abatement activities themselves might have increased blood lead levels because the small transient increase in blood lead was not significant, and there was no dose-response pattern. Also, as expected, the correlation between blood lead and soil lead did not show a sudden increase immediately after abatement. More probable explanations for the slower decline in blood lead levels in children with abatement include selection bias, soil mixing, and recontamination by a neighborhood source.

Selection of children for the blood sampling was most likely responsible, at least in part, for the worst time trend being found among abatement children. It was implicated by poor response rates, which worsened over time, and by use of postulated blood lead values for the missing children. It was interesting that even the simulated results did not support the conclusion that abatement was beneficial to individuals. Also, it is likely that there was bias in who did and did not consent to abatement, although its impact was difficult to determine.

Mixing of soil in the children's yards might have occurred over time; lead in soil at a depth greater than 30 cm might have contaminated the upper replacement soil. Previously, it has been reported that mixing occurs when only 15 cm is replaced[26]; therefore, a depth of 30 cm was adopted for the current abatement project. Additional sampling of soil in SR was undertaken in

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